

CLAIMS

What is claimed is:

1. A method for fabricating a self-aligned gated carbon nanotube field emitter structure, comprising the steps of:
 - providing a substrate, wherein the substrate has a surface;
 - depositing a dielectric material on the surface of the substrate, wherein the dielectric material has a surface;
 - depositing a conductor layer on the surface of the dielectric material, wherein the conductor layer has a surface;
 - selectively etching the conductor layer to form an opening in the conductor layer;
 - selectively etching the dielectric material to form a micro-cavity in the dielectric material;
 - depositing a base layer structure in the micro-cavity adjacent to the surface of the substrate, wherein the base layer structure has a surface, and wherein the base layer structure has a substantially conical shape;
 - depositing a catalyst on a portion of the surface of the base layer structure, wherein the catalyst is suitable for growing at least one carbon nanotube;
 - applying an electrical potential to the substrate and the conductor layer, wherein the electrical potential generates a plurality of electrical field lines that are deflected around the surface of the base layer structure, and wherein the plurality of electrical field lines have a strength that is greatest in a direction substantially perpendicular to the surface of the substrate; and
 - growing at least one carbon nanotube from the catalyst in the presence of the plurality of electrical field lines, wherein the at least one carbon nanotube is grown in a direction substantially perpendicular to the surface of the substrate.
2. The method of claim 1, wherein the substrate comprises at least one of a metal, a semiconductor material, a metal deposited on a glass and a semiconductor material deposited on a glass.

3. The method of claim 1, wherein the dielectric material comprises at least one of an oxide, a nitride and a combination thereof.
4. The method of claim 3, wherein the oxide comprises at least one of SiO_2 , Al_2O_3 and a combination thereof.
5. The method of claim 3, wherein the nitride comprises SiN_x , wherein $0.5 \leq x \leq 1.5$.
6. The method of claim 1, wherein the conductor layer comprises at least one of a metal and a semiconductor material.
7. The method of claim 6, wherein the metal comprises at least one of Mo, Pt, Al, Ti and a combination thereof.
8. The method of claim 6, wherein the semiconductor material comprises at least one of doped amorphous silicon and doped poly-silicon.
9. The method of claim 1, further comprising depositing a sacrificial layer on a portion of the surface of the conductor layer, wherein the sacrificial layer has a surface.
10. The method of claim 9, wherein the sacrificial layer comprises at least one of a metal, a semiconductor, an evaporated dielectric and a photoresist.
11. The method of claim 9, wherein the sacrificial layer is deposited on a portion of the surface of the conductor layer at a predetermined angle.
12. The method of claim 11, wherein the sacrificial layer is deposited on a portion of the surface of the conductor layer while the substrate is rotating at a predetermined rotational speed.

13. The method of claim 9, further comprising depositing a base layer on the surface of the sacrificial layer and a portion of the surface of the substrate, wherein the base layer has a surface, and wherein the base layer deposited on the portion of the surface of the substrate forms the base layer structure.
14. The method of claim 13, wherein the base layer comprises at least one of a metal and doped silicon.
15. The method of claim 1, wherein the base layer structure comprises at least one of a metal and doped silicon.
16. The method of claim 13, further comprising depositing the catalyst on a portion of the surface of the base layer.
17. The method of claim 16, further comprising removing the sacrificial layer, the corresponding base layer deposited on the surface of the sacrificial layer and the corresponding catalyst deposited on the surface of the base layer.
18. The method of claim 1, wherein the catalyst comprises at least one transition metal.
19. The method of claim 18, wherein the at least one transition metal comprises at least one of Ni, Fe and Co.
20. The method of claim 1, wherein the electrical potential applied to the substrate and the conductor layer is between about 0.1 V and about 5 V.
21. The method of claim 1, wherein the electric potential induces an electric field of at least 10^3 V/cm on the substantially conical shape.

22. The method of claim 1, wherein the at least one carbon nanotube has a length of between about 50 nm and about 1,000 nm.
23. The method of claim 22, wherein the at least one carbon nanotube has a length of between about 100 nm and about 500 nm.
24. The method of claim 1, wherein the at least one carbon nanotube comprises at least one of a single-walled carbon nanotube, a double-walled carbon nanotube and a multi-walled carbon nanotube.
25. The method of claim 1, wherein the step of growing the at least one carbon nanotube comprises growing the at least one carbon nanotube by chemical vapor deposition.
26. The method of claim 25, wherein the step of growing the at least one carbon nanotube by chemical vapor deposition comprises growing the at least one carbon nanotube in a chemical vapor deposition tube coupled to a flowing carbon source.
27. The method of claim 26, wherein the flowing carbon source is one of a methane source, an acetylene source and a combination thereof.
28. The method of claim 25, wherein the step of growing the at least one carbon nanotube by chemical vapor deposition comprises growing the at least one carbon nanotube by chemical vapor deposition at a temperature of between about 700 degrees C and about 1,000 degrees C.
29. The method of claim 1, wherein the at least one carbon nanotube comprises at least one of a metallic-type carbon nanotube and a semiconducting-type carbon nanotube.
30. The method of claim 1, wherein each of the depositing steps comprises a deposition technique selected from the group consisting of sputtering, thermal

evaporation, electron-beam evaporation, chemical vapor deposition, plasma-enhanced chemical vapor deposition, low-pressure chemical vapor deposition and thermal oxide growth.

31. The method of claim 1, wherein the self-aligned gated carbon nanotube field emitter structure comprises a triode carbon nanotube field emitter structure.

32. A method for fabricating a triode carbon nanotube field emitter structure, comprising the steps of:

providing a cathode electrode, wherein the cathode electrode has a surface;

depositing a dielectric layer on the surface of the cathode electrode, wherein the dielectric layer has a surface;

depositing a gate electrode on the surface of the dielectric layer, wherein the gate electrode has a surface;

selectively etching the gate electrode to form an opening in the gate electrode;

selectively etching the dielectric layer to form a micro-cavity in the dielectric layer;

depositing a conductive base layer structure in the micro-cavity adjacent to the surface of the cathode electrode, wherein the conductive base layer structure has a surface, and wherein the conductive base layer structure has a substantially conical shape;

depositing a catalyst on a portion of the surface of the conductive base layer structure, wherein the catalyst is suitable for growing at least one carbon nanotube;

applying an electrical potential to the cathode electrode and the gate electrode, wherein the electrical potential generates a plurality of electrical field lines that are deflected around the surface of the conductive base layer structure, and wherein the plurality of electrical field lines have a strength that is greatest in a direction substantially perpendicular to the surface of the cathode electrode; and

growing at least one carbon nanotube from the catalyst in the presence of the plurality of electrical field lines, wherein the at least one carbon nanotube is grown in a direction substantially perpendicular to the surface of the cathode electrode.

33. The method of claim 32, wherein the cathode electrode comprises at least one of a metal, a semiconductor material, a metal deposited on a glass and a semiconductor material deposited on a glass.
34. The method of claim 32, wherein the dielectric material comprises at least one of an oxide, a nitride and a combination thereof.
35. The method of claim 34, wherein the oxide comprises at least one of SiO_2 , Al_2O_3 and a combination thereof.
36. The method of claim 34, wherein the nitride comprises SiN_x , wherein $0.5 \leq x \leq 1.5$.
37. The method of claim 32, wherein the gate electrode comprises at least one of a metal and a semiconductor material.
38. The method of claim 32, further comprising depositing a sacrificial layer on a portion of the surface of the gate electrode, wherein the sacrificial layer has a surface.
39. The method of claim 38, wherein the sacrificial layer comprises at least one of a metal, a semiconductor, an evaporated dielectric and a photoresist.
40. The method of claim 38, wherein the sacrificial layer is deposited on a portion of the surface of the gate electrode at a predetermined angle.
41. The method of claim 40, wherein the sacrificial layer is deposited on a portion of the surface of the gate electrode while the cathode electrode is rotating at a predetermined rotational speed.
42. The method of claim 38, further comprising depositing a conductive base layer on the surface of the sacrificial layer and a portion of the surface of the cathode electrode, wherein the conductive base layer has a surface, and wherein the

conductive base layer deposited on the portion of the surface of the cathode electrode forms the conductive base layer structure.

43. The method of claim 42, wherein the conductive base layer comprises at least one of a metal and doped silicon.
44. The method of claim 32, wherein the conductive base layer structure comprises at least one of a metal and doped silicon.
45. The method of claim 42, further comprising depositing the catalyst on a portion of the surface of the conductive base layer.
46. The method of claim 45, further comprising removing the sacrificial layer, the corresponding conductive base layer deposited on the surface of the sacrificial layer and the corresponding catalyst deposited on the surface of the conductive base layer.
47. The method of claim 32, wherein the catalyst comprises a material comprising at least one transition metal.
48. The method of claim 47, wherein the at least one transition metal comprises at least one of Ni, Fe and Co.
49. The method of claim 32, wherein the electrical potential applied to the cathode electrode and the gate electrode is between about 0.1 V and about 5 V.
50. The method of claim 32, wherein the electrical potential induces an electric field of at least 10^3 V/cm on the substantially conical shape.
51. The method of claim 32, wherein the at least one carbon nanotube has a length of between about 50 nm and about 1,000 nm.

52. The method of claim 51, wherein the at least one carbon nanotube has a length of between about 100 nm and about 500 nm.
53. The method of claim 32, wherein each of the depositing steps comprises a deposition technique selected from the group consisting of sputtering, thermal evaporation, electron-beam evaporation, chemical vapor deposition, plasma-enhanced chemical vapor deposition, low-pressure chemical vapor deposition and thermal oxide growth.
54. The method of claim 32, wherein the step of growing the at least one carbon nanotube comprises growing the at least one carbon nanotube by chemical vapor deposition.
55. The method of claim 54, wherein the step of growing the at least one carbon nanotube by chemical vapor deposition comprises growing the at least one carbon nanotube in a chemical vapor deposition tube coupled to a flowing carbon source.
56. The method of claim 55, wherein the flowing carbon source is one of a methane source, an acetylene source and a combination thereof.
57. The method of claim 54, wherein the step of growing the at least one carbon nanotube by chemical vapor deposition comprises growing the at least one carbon nanotube by chemical vapor deposition at a temperature of between about 700 degrees C and about 1,000 degrees C.
58. A self-aligned gated carbon nanotube field emitter structure fabricated by a process comprising the steps of:
- providing a substrate, wherein the substrate has a surface;
 - depositing a dielectric material on the surface of the substrate, wherein the dielectric material has a surface;
 - depositing a conductor layer on the surface of the dielectric material, wherein the conductor layer has a surface;

selectively etching the conductor layer to form an opening in the conductor layer;

selectively etching the dielectric material to form a micro-cavity in the dielectric material;

depositing a base layer structure in the micro-cavity adjacent to the surface of the substrate, wherein the base layer structure has a surface, and wherein the base layer structure has a substantially conical shape;

depositing a catalyst on a portion of the surface of the base layer structure, wherein the catalyst is suitable for growing at least one carbon nanotube;

applying an electrical potential to the substrate and the conductor layer, wherein the electrical potential generates a plurality of electrical field lines that are deflected around the surface of the base layer structure, and wherein the plurality of electrical field lines have a strength that is greatest in a direction substantially perpendicular to the surface of the substrate; and

growing at least one carbon nanotube from the catalyst in the presence of the plurality of electrical field lines, wherein the at least one carbon nanotube is grown in a direction substantially perpendicular to the surface of the substrate.

59. The structure of claim 58, wherein the substrate comprises at least one of a metal, a semiconductor material, a metal deposited on a glass and a semiconductor material deposited on a glass.

60. The structure of claim 58, wherein the dielectric material comprises at least one of a metal oxide, a metal nitride and a combination thereof.

61. The structure of claim 60, wherein the metal oxide comprises at least one of SiO_2 , Al_2O_3 and a combination thereof.

62. The structure of claim 60, wherein the metal nitride comprises SiN_x , wherein $0.5 \leq x \leq 1.5$.

63. The structure of claim 58, wherein the conductor layer comprises at least one of a metal and a semiconductor material.
64. The structure of claim 58, wherein the process further comprises depositing a sacrificial layer on a portion of the surface of the conductor layer, wherein the sacrificial layer has a surface.
65. The structure of claim 64, wherein the sacrificial layer comprises at least one of a metal, a semiconductor, an evaporated dielectric and a photoresist.
66. The structure of claim 64, wherein the sacrificial layer is deposited on a portion of the surface of the conductor layer at a predetermined angle.
67. The structure of claim 66, wherein the sacrificial layer is deposited on a portion of the surface of the conductor layer while the substrate is rotating at a predetermined rotational speed.
68. The structure of claim 64, wherein the process further comprises depositing a base layer on the surface of the sacrificial layer and a portion of the surface of the substrate, wherein the base layer has a surface, and wherein the base layer deposited on the portion of the surface of the substrate forms the base layer structure.
69. The structure of claim 68, wherein the base layer comprises at least one of a metal and doped silicon.
70. The structure of claim 58, wherein the base layer structure comprises at least one of a metal and doped silicon.
71. The structure of claim 68, wherein the process further comprises depositing the catalyst on a portion of the surface of the base layer.

72. The structure of claim 58, wherein the catalyst comprises a material comprising at least one transition metal.
73. The structure of claim 72, wherein the transition metal comprises at least one of Ni, Fe and Co.
74. The structure of claim 71, wherein the process further comprises removing the sacrificial layer, the corresponding base layer deposited on the surface of the sacrificial layer and the corresponding catalyst deposited on the surface of the base layer.
75. The structure of claim 58, wherein the electrical potential applied to the substrate and the conductor layer is between about 0.1 V and about 5 V.
76. The structure of claim 58, wherein the electrical potential induces an electric field of at least 10^3 V/cm on the substantially conical shape.
77. The structure of claim 58, wherein the at least one carbon nanotube has a length of between about 50 nm and about 1,000 nm.
78. The structure of claim 77, wherein the at least one carbon nanotube has a length of between about 100 nm and about 500 nm.
79. The structure of claim 58, wherein the at least one carbon nanotube comprises at least one of a single-walled carbon nanotube and a multi-walled carbon nanotube.
80. The structure of claim 58, wherein the at least one carbon nanotube comprises at least one of a metallic-type carbon nanotube and a semiconducting-type carbon nanotube.
81. The structure of claim 58, wherein each of the depositing steps comprises a deposition technique selected from the group consisting of sputtering, thermal

evaporation, electron-beam evaporation, chemical vapor deposition, plasma-enhanced chemical vapor deposition, low-pressure chemical vapor deposition and thermal oxide growth.

82. The structure of claim 58, wherein the at least one carbon nanotube is grown by chemical vapor deposition.
83. The structure of claim 58, wherein the self-aligned gated carbon nanotube field emitter structure comprises a triode carbon nanotube field emitter structure.
84. A triode carbon nanotube field emitter structure, comprising:
a cathode electrode, wherein the cathode electrode has a surface;
a dielectric layer disposed adjacent to a portion of the surface of the cathode electrode, wherein the dielectric layer has a surface, and wherein an interior portion of the dielectric layer defines a micro-cavity;
a gate electrode disposed adjacent to the surface of the dielectric layer, wherein the gate electrode has a surface, and wherein an interior portion of the gate electrode defines an opening substantially aligned with the micro-cavity defined by the interior portion of the dielectric layer;
a conductive base layer structure disposed adjacent to a portion of the surface of the cathode electrode within the micro-cavity defined by the interior portion of the dielectric layer and substantially aligned with the opening defined by the interior portion of the gate electrode, wherein the conductive base layer structure has a surface, and wherein the conductive base layer structure has a substantially conical shape; and
at least one carbon nanotube disposed adjacent to a portion of the surface of the conductive base layer structure, wherein the at least one carbon nanotube is substantially perpendicularly aligned with the surface of the cathode electrode.
85. The structure of claim 84, wherein the cathode electrode comprises at least one of a metal, a semiconductor material, a metal deposited on a glass and a semiconductor material deposited on a glass.

86. The structure of claim 84, wherein the dielectric layer comprises at least one of a metal oxide, a metal nitride and a combination thereof.
87. The structure of claim 86, wherein the metal oxide comprises at least one of SiO_2 , Al_2O_3 and a combination thereof.
88. The structure of claim 86, wherein the metal nitride comprises SiN_x , wherein $0.5 \leq x \leq 1.5$.
89. The structure of claim 84, wherein the gate electrode comprises at least one of a metal and a semiconductor material.
90. The structure of claim 84, wherein the conductive base layer structure comprises at least one of a metal and doped silicon.
91. The structure of claim 84, wherein the at least one carbon nanotube has a length of between about 50 nm and about 1,000 nm.
92. The structure of claim 91, wherein the at least one carbon nanotube has a length of between about 100 nm and about 500 nm.
93. The structure of claim 84, wherein the triode carbon nanotube field emitter structure is suitable for use in an application selected from the group consisting of an x-ray imaging application, a flat panel field emission display application, a microwave power amplifier application, a lighting application and an electron-beam lithography application.
94. An electronic system, the electronic system having an emissive device, the emissive device comprising at least one triode carbon nanotube field emission device, wherein the at least one triode carbon nanotube field emission device comprises:

a cathode electrode, wherein the cathode electrode has a surface;

a dielectric layer disposed adjacent to a portion of the surface of the cathode electrode, wherein the dielectric layer has a surface, and wherein an interior portion of the dielectric layer defines a micro-cavity;

a gate electrode disposed adjacent to the surface of the dielectric layer, wherein the gate electrode has a surface, and wherein an interior portion of the gate electrode defines an opening substantially aligned with the micro-cavity defined by the interior portion of the dielectric layer;

a conductive base layer structure disposed adjacent to a portion of the surface of the cathode electrode within the micro-cavity defined by the interior portion of the dielectric layer and substantially aligned with the opening defined by the interior portion of the gate electrode, wherein the conductive base layer structure has a surface, and wherein the conductive base layer structure has a substantially conical shape; and

at least one carbon nanotube disposed adjacent to a portion of the surface of the conductive base layer structure, wherein the at least one carbon nanotube is substantially perpendicularly aligned with the surface of the cathode electrode.

95. The electronic system of claim 94, wherein the electronic system comprises an imaging system.

96. The electronic system of claim 95, wherein the imaging system comprises an x-ray imaging system.

97. The electronic system of claim 94, wherein the electronic system comprises a fluorescent lighting system.

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98. The electronic system of claim 94, wherein the electronic system comprises at least one of an x-ray source, a lighting device, a flat panel display, a microwave power amplifier and an electron-beam lithography device.